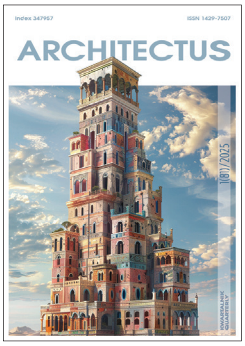


Architectus

2025
1(81)

DOI: 10.37190/arc250112


**Ewa Szymczyk*, Mateusz Bukowski****

# *Compactness of Polish urban areas – methodologies and analysis based on CLC dataset*

***Abstract***

This research delves into the dynamics of urban compactness in Poland, exploring methodologies for analysis and assessing changes over time. Three key research questions guiding the study revolve around methods for compactness analysis, the relationship between the size of urban municipalities and compactness, and temporal changes.

The research considers all Polish municipalities and analyses selected compactness measures in 2006, 2012 and 2018. By evaluating various analytical approaches and utilising land use data from CLC (CORINE Land Cover), the study provides a new methodology to monitor city compactness measures, thus contributing to evidence-based decision-making for sustainable urban planning.

The outcomes unveil patterns and correlations across city sizes and temporal trends, showing the decrease in compactness over time. It reveals a logarithmic relation between population size, compactness index, and urban population density. While smaller cities tend to be more compact in shape, they are less dense. Conversely, larger cities tend to be more densely populated but also more spatially dispersed. This study contributes to the state of knowledge by introducing and testing a method to assess urban compactness across urban areas. Since the CLC datasets cover the entire European Union, this method is replicable in every member state, allowing for further comparative studies.

**Key words:** Poland, compactness, urban population density, CLC, urban form measures

## *Introduction*

There has been a growing interest in urban patterns in European and North American literature, specifically focusing on quantitative methods (Reis, Silva and Pinho 2016). The emphasis on sustainable development models, the advancement of GIS tools and information technology, and the increased availability and quality of spatial data have led to a rapid acceleration of data-driven spatial research across various domains. Geographers, environmental scientists, economists, and policymakers have all analysed the relationships with spatial patterns. Spatial indicators are crucial in examining the connections between the built environment and different urban processes. It is similar in urban science, where spatial measures are essential for monitoring the development of spatial organisation within cities over time, allowing for analysing and comparing spatial-temporal patterns. While numerous methods are available for such analyses, the choice of method is typically influenced by its relevance to the specific question.

Urban form measures have become a central focus in the study of urban compactness, an urban form characteristic strongly linked to sustainable development (OECD 2012) and seen as the opposite of urban sprawl (Tsai 2005). At the same time, urban sprawl is known to have high social costs in urban planning (Squires 2002; Schwarz, Haase and Seppelt 2010; Siedentorp, Fina 2010; UN-HABITAT 2022); recent research suggests that urban forms significantly impact commuting patterns (Song et al. 2017). According to Schiller and Kenworthy (2018), this development pattern also leads to increased costs, adverse effects on the city centre, higher energy and fuel consumption, and detrimental effects on household budgets and the environment. In a study on the relationship between urban sprawl and

* ORCID: 0000-0003-3698-3478. Faculty of Architecture and Urban Planning, Cracow University of Technology, Poland, e-mail: ewa.szymczyk@pk.edu.pl

** ORCID: 0009-0001-0285-8241. Independent researcher, Switzerland.

economic performance in growing Polish cities, Lityński (2021) found that stronger local economies are associated with less urban sprawl. Conversely, high urban compactness and high urban density are believed to benefit public transit systems (OECD 2012; Schiller, Kenworthy 2018).

The concept of the compact city is one of the most widely discussed in contemporary urban policy (OECD 2012). The term compact city was first used by Dantzig and Saaty (1973), who were principally interested in a more efficient use of urban resources. It is recommended for urban development at all levels of planning guidelines, from global organisations like the UN-HABITAT to the European Union and in Polish national planning documents (Uchwała 2015). Compactness can be measured in various ways but generally relates to urban expansion and density patterns. The OECD defines the characteristics of the compact city as […] *dense and proximate development patterns* […] *urban areas linked by public transport systems* […] *accessibility to local services and jobs* (OECD 2012, 15). Understanding urban compactness is crucial for addressing urban sprawl and promoting and effectively planning sustainable urban development globally and locally. Since this concept in Poland was mainly analysed from the perspective of the opposite phenomenon of urban sprawl and never from a nationwide scale, this study fills this gap. It aims to achieve the methodological and empirical objectives of assessing urban compactness in Poland. This aim is achieved by addressing three key research questions:

1. What are the methods for analysing compactness?
2. What is the relationship between city size and city compactness in Poland?
3. How does compactness change over time in Polish cities?

The research assesses various methods for analysing urban compactness, including morphological indices and computational models, and their relevance in the context of Poland. It suggests a methodology based on the CLC (CORINE Land Cover), a crucial data source on Europe's land use and landscape dynamics. The study applies two methods to assess the compactness of all municipalities in Poland. It uses historical CLC data to explore the evolution of urban compactness in all Polish urban areas (in all municipalities) and separately only for urban areas in cities (urban and urban-rural municipalities) and its relationship to the municipality population size.

## *State of research*

Ahlfeldt and Pietrostefani (2017) reviewed the theoretical literature and identified three main characteristics of compact cities: economic density, morphological density, and mixed land use. Each of these characteristics can be measured in various ways. Economic density, the number of people or jobs within a given area, is typically measured using population or employment density (Ahlfeldt, Pietrostefani 2017). Morphological density focuses on the built environment and includes measures such as urban/rural boundaries, street connectivity, and building footprint-to-parcel ratio. Mixed land use captures the co-location of different functions, such as residential, employment, and retail. It can be measured in two dimensions (Ahlfeldt, Pietrostefani 2017) or vertically (in three dimensions) (Burton 2002). When considering the concept of a compact city, it is essential to select measures and methods based on their relevance to the specific question being addressed, available data and the scale of the analysis (Ottensmann 2021).

A study on spatial metrics conducted by Reis et al. (2015) provides an extensive overview of all measures and methods to study patterns of urban growth and shrinkage. Authors subdivided patterns of growth into four main groups:

1) expansion,
2) urban sprawl,
3) polycentrism,
4) densification/coalescence.

According to their review, urban sprawl is the most studied pattern in Planning and Geography. While the exact definition is ambiguous, it is commonly understood as characterised by scatter/fragmentation, low density (both population and building), single-use and poor accessibility (Reis et al. 2015). Compactness, seen as the opposite of urban sprawl, may be measured similarly.

The most commonly used measure of compactness is related to density (Burton 2002). Most known research uses population density (for example, Newman and Kenworthy 1989). When it comes to spatial measures, the compact city concept typically concerns the two-dimensional expansion pattern of an urbanised area, which is considered more compact if the pattern is more clustered towards a centre and with less sprawl, leap-frogging or branching (Mubareka et al. 2011). Referring to Reis et al. (2015) classification of metrics, the analysis can use one of three metrics groups depending on the area of knowledge and methodological approach to urban form. These groups are Landscape metrics, Geospatial metrics and Spatial metrics. Categories organise each of these groups and consist of numerous metrics to investigate them. Figure 1 shows how the selected shape metrics fit into the classification.

Ottensmann (2021) conducted a study on the urban shape of 59 large cities in the US, evaluating measures based on specific criteria. The author identified three crucial aspects for determining the most suitable shape indices: the ability of metrics to measure the relation to the city centre or CBD (Central Business District in the US), the method of measuring holes and discontinuous areas, and the applicability to given urban area data. The study reviewed shape measures that assess the compactness of urban areas, assuming that the circle is the most compact 2D shape. In his research on large US cities, Ottensmann used the Proximity Index (belonging to the "Distances to Areas in the Shape" category). This landscape metric measures shape irregularity by calculating the distance from all locations within the urban area to the CBD. The author points out that this method is suitable when only one centre can be identified but is not useful for polycentric urban areas.

Similarly, Burton (2002) studied English compactness, selecting 25 towns, medium-sized, and big cities. However, Burton developed a multi-criteria indicator method. Indicators were organised into six groups: compactness,

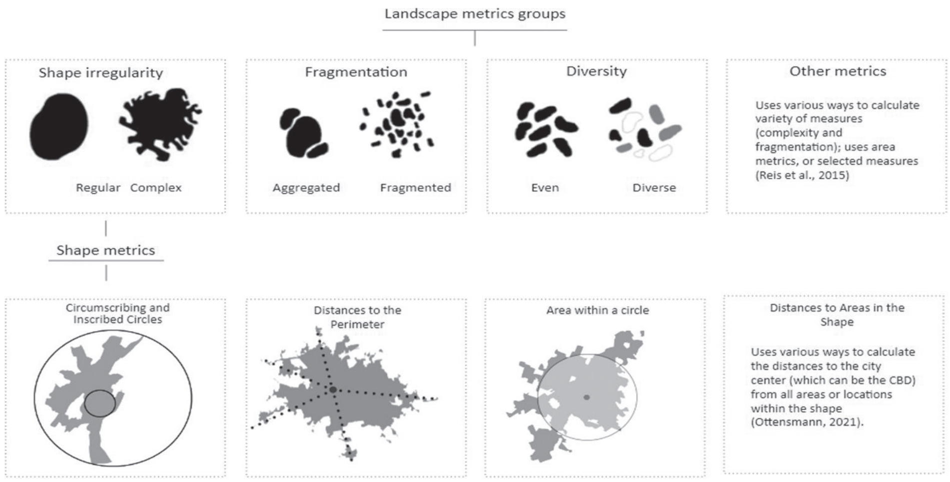


Fig. 1. Landscape metrics groups and shape metrics categories (elaborated by E. Szymczyk, based on Reis et al. 2015; Ottensmann 2021)

Il. 1. Grupy metryk przestrzennych i kategorie metryk kształtu (oprac. E. Szymczyk, na podstawie Reis et al. 2015 oraz Ottensmann 2021)

density, mixed-use, intensification, population intensification, and built-form intensification, each with four variables. While the measures of compactness objectively represented the phenomenon, the author concluded that they may not always accurately represent subjective compactness. This supports the idea that compactness is a sociocultural construct rather than a purely objective one.

Thinh et al. (2002) research on the compactness of 116 German cities was driven by the question of how compact a sustainable city is. The authors used data from the CLC and the Digital Landscape Model (DLM) of Germany to establish and validate the degree of surface sealing (in percentage). They established a GIS raster analysis using a square raster (500/500 m grid) and the gravitational approach (Thinh et al. 2002). Their research presented a connection between various socio-environmental indicators and the compactness of city form.

In the literature about Polish cities, there is a significant focus on urban sprawl. Urban compactness is primarily examined in terms of urban density. Śleszynski (2014) conducted the most extensive study on urban population density in 147 Polish cities. His analysis utilised data from the 2002 census, which divided cities with over 30,000 inhabitants into statistical districts, enabling more in-depth studies on population distribution within cities. The key findings are related to the distribution of density from the city centre, revealing a strong correlation between population density in the 0–2 km concentration zone from the city centre and the demographic sizes of towns or cities. Smaller cities and towns generally have less dense centres compared to larger ones. Lityński (2021) conducted a major study on urban sprawl in relation to economic performance. The Author analysed 4 big Polish cities and their neighbouring municipalities. The method used to assess urban sprawl is based on the following indicators: density, continuity, concentration, clustering and centrality. Higher ratios indicate less urban sprawl. Density, for example, is the number of housing units per hectare of urbanised land[1] and centrality is the degree to which buildings are located in relation to the city centre. It calculates the distance from the village centre to the city centre. The measure is the inverse of the average sum of these distances weighted by the number of housing units in the village.

The methods listed above answer the first research question by demonstrating the various ways compactness can be measured, depending on the specific focus of the research. The next sections of this study add to the methodologies for measuring the compact city by offering a technique that utilises open-source spatial data (CLC) and statistical population data.

## *Data and methods*

This study adopts a quantitative approach to examine Poland's urban municipalities from the perspective of 12 years. The selection of subjects is based on Poland's administrative system. On the highest/regional level, there is a voivodeship (województwo), which consists of counties (powiat); counties are divided into individual local-authority municipalities (gmina); a municipality contains either an individual city, which by GUS (Główny Urząd Statystyczny, Eng. Statistics Poland) classification: level 6, kind 1), only villages – rural area (GUS classification: level 6, kind 2), or a mix of a town and villages – urban-rural area (GUS classification: level 6, kind 3) (GUS BDL 2023). The selected method uses the smallest local government unit, i.e., the municipality (gmina). In 2021, Poland had 2,477 municipalities: 302 urban, 662 urban-rural and 1,513 rural. Therefore, the analysis is divided into three administrative categories:

– an urban area in the urban municipality (GUS level 6, kind 1),

– an urban area in the urban-rural municipality (GUS level 6, kind 3), including a city and small settlements,

– an urban area in a rural municipality (GUS level 6, kind 2), including towns and small settlements.

The varying spatial units over different years in Poland were carefully considered to maintain data consistency. Additionally, to see the possible linkage with the size of urban areas, this study relied on a simplified division based on Statistics Poland's categorisation:

[1] Author calls it Developable land (DL) which is an area that is the difference between the total municipal area and the sum of land covered by water, forest, recreation areas, roads and land reserved for ecological purposes (Lityński 2021).

Table 1. CLC Codes indicate classes taken under consideration and their respective colours (source: CLC 2023)

Tabela 1. Kody CLC wskazujące klasy uwzględnione w analizie oraz odpowiadające im kolory (źródło: CLC 2023)

| | CLC Code | Name |
|---|---|---|
| | 111 | Continuous urban fabric |
| | 112 | Discontinuous urban fabric |
| | 121 | Industrial or commercial units |
| | 122 | Road and rail networks and associated land |
| | 123 | Port areas |
| | 124 | Airports |
| | 131 | Mineral extraction sites |
| | 132 | Dump sites |
| | 133 | Construction sites |
| | 141 | Green urban areas |
| | 142 | Sport and leisure facilities |

– below 20,000 as a small city,
– 20,000–100,000 as a medium city and
– above 100,000 a big city.

The population was categorised based on the year of the spatial analysis data.

The timeframe of our study was chosen for two reasons: first, because the most recent data available at the time was provided for 2018, and second, to see urban areas for an extended amount of time after the European Union accession (in 2004). The data for urban spatial metrics is based on land use data from the CLC for the area of Poland. The CLC data is a standardised methodology for producing continent-scale land cover, biotope, and air quality maps, including 44 land-use classes. Since the product is updated every six years, with the most recent update being in 2018, the three data sets were selected: CLC2006, CLC2012, and CLC2018.

To define the shape of the urban area, the 44 classes of land used by the CLC were considered. Urban areas were broadly defined as "artificial surfaces" (CLC), which include infrastructure and green urban areas, represented by 11 classes (Table 1). This method is similar to the one followed by the GUGiK (Główny Urząd Geodezji i Kartografii, Eng. Geodesy and Cartography Poland) (GUGiK 2024). While most of the population lives in the first two "urban areas" classes (111, 112), the remaining nine classes represent urbanised areas, which are an integral part of the city.

The selected classes were cut to the municipality's boundaries and merged into one shape consisting of one or more polygons (Fig. 2). Each shape received a unique identification number of a spatial unit, called TERYT

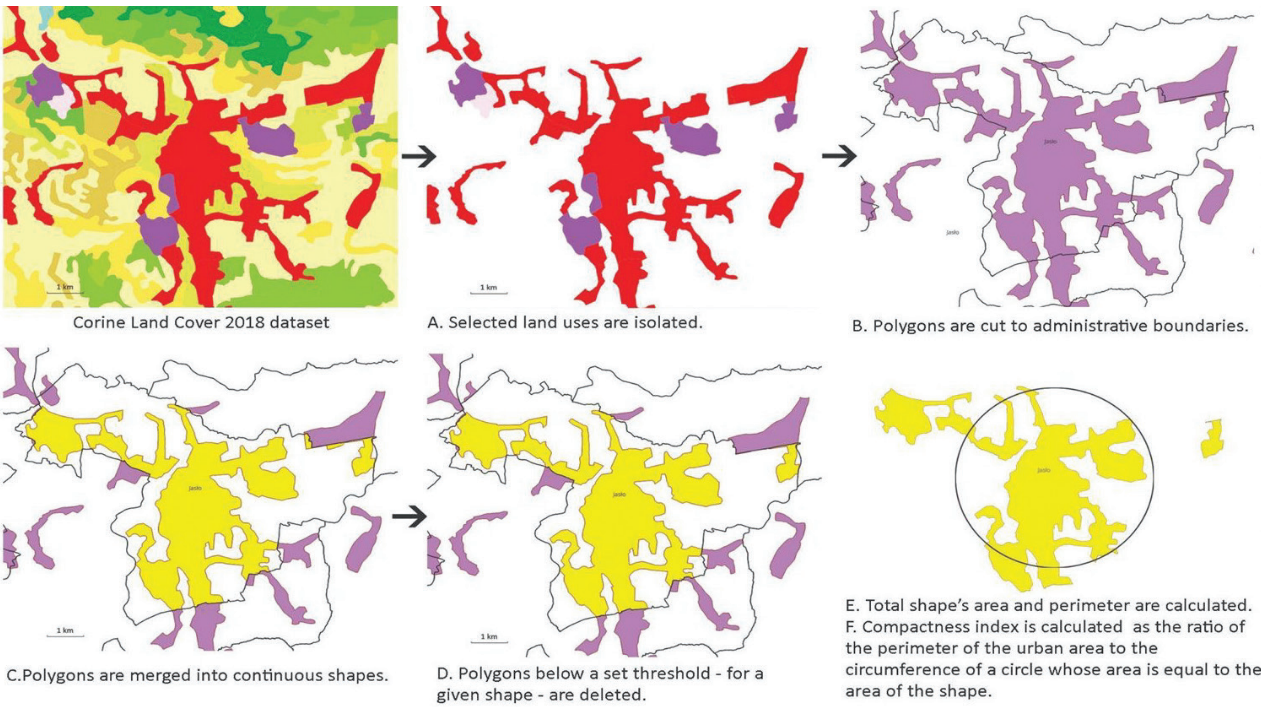


Fig. 2. Diagram presenting a step-by-step spatial analysis method, defining compactness index and urban population density based on Jasło (elaborated by E. Szymczyk)

Il. 2. Schemat przedstawiający metodę analizy przestrzennej, definiującą indeks zwartości (Ci) oraz gęstość zaludnienia obszarów miejskich (Ud) na przykładzie Jasła (oprac. E. Szymczyk)

(Krajowy rejestr urzędowy podziału terytorialnego kraju, eng. National Official Register of the Territorial Division of the Country). Moreover, the development of the analytical method included some calibrations. Due to some discrepancies in the spatial data (such as imprecise land use demarcation), many cities had minor shapes left after cutting to the boundaries. After analysing possible thresholds to avoid distorting the calculation, a threshold of 2% of the total shape area was set. All the shapes that were below this value were deleted (step D).

The calculation consists of the following operations for each selected year:

A. Isolation of selected 11 land use classes.

B. A cut of land use polygons with city administrative boundaries.

C. Merge polygons into continuous shapes.

D. Delete polygons below a set threshold – for a given shape.

E. Calculate the shape's area and perimeter.

F. Calculate the compactness index.

G. Calculate the urban population density.

As presented in State of research section, there are multiple ways to measure urban area compactness. This study uses the urban compactness (Ci) and urban density (Ud) index with values in persons per square kilometre.

The compactness index quantifies the compactness of shapes' irregularity. There are many measures of the compactness index (Niemi et al. 1990; Altman 1998; Chambers, Miller 2010). A few were identified by Barnes and Solomon (2021) as the most commonly used. Among these most common, the authors selected a single measure named Schwartzberg (1966). The Schwartzberg compactness index is determined by comparing the perimeter (*Pd*) of an urban area (see Fig. 2) to the circumference of a circle that has the same area (*Ad*) as the urban area. It can be expressed as follows:

$$Ci = \frac{1}{\frac{P_d}{2\pi\sqrt{A_d/\pi}}}$$

Index ranges from 0 to 1, where 0 is the least compact and 1 is the most compact. This index was calculated for each medium-sized city in each CLC year.

The second measure considers the urban area (*Ua*) and the municipality population (*Pop*) in the corresponding year to calculate the urban population density. Compared to the simplified population density found in GUS, this method of selecting urban areas excludes agricultural land, forests and water bodies, among others, giving a more accurate picture of where the city urbanised boundaries. The urban population density (*Ud*) can be formally written as:

$$Ud = \frac{Pop}{Ua}$$

## *Results*

This section presents the analysis outcomes for all municipalities (2477) and separately only for urban municipalities (964) in three periods based on the CLC datasets. The outcomes are divided into three relations:

– trends in time,

– trends concerning city size,

– trends concerning the location.

Firstly, the compactness index (Ci) of urbanised areas in Polish municipalities shows a decreasing trend over time. This is true when urban areas in all municipalities are considered (Fig. 3a) and when only the urban municipalities (Kind 1, Kind 3 in GUS) are taken into consideration (Fig. 3b). On average, urban municipalities were more compact than rural ones. Table 2 shows detailed analysis outcomes, revealing the decrease in the Ci of urban areas in urban municipalities. The most compact Polish urban municipalities in 2006 were Ząbki, Podkowa Leśna and Wysokie Mazowieckie in 2012 and in 2018, it was Zawidów, Wysokie Mazowieckie and Podkowa Leśna with over 0,6 Ci. All the top-scoring cities are small (except for Ząbki, a medium-sized city), and all are adjacent to a big urban area.

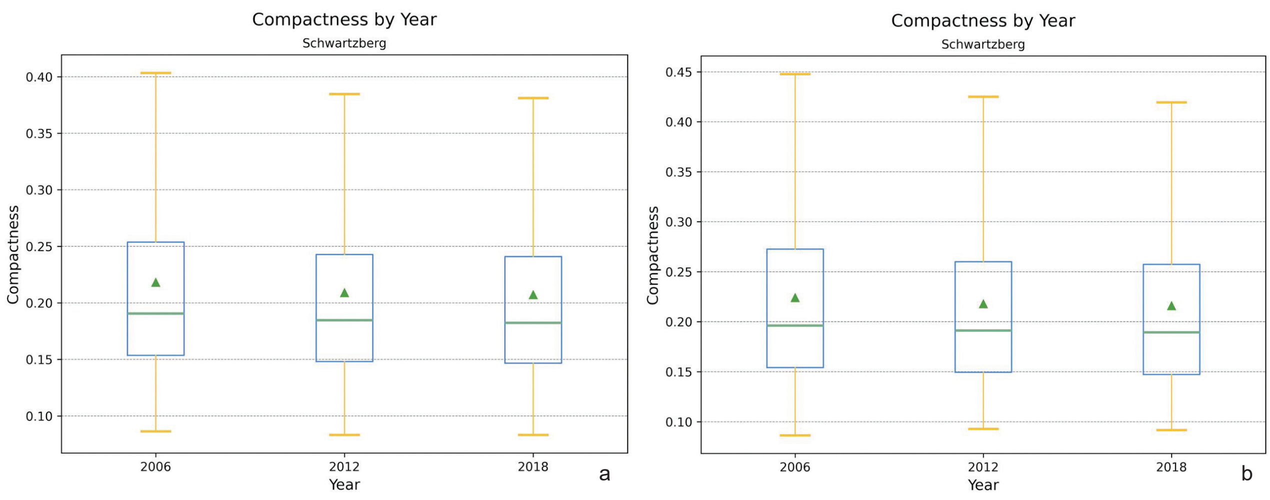


Fig. 3. Compactness index trend for: a) all Polish municipalities, b) all urban municipalities (elaborated by M. Bukowski, E. Szymczyk)

Il. 3. Trend indeksu zwartości dla wszystkich polskich: a) gmin, b) gmin miejskich (oprac. M. Bukowski, E. Szymczyk)

Table 2. Outcomes of urban population density analysis for all urban municipalities (elaborated by E. Szymczyk)
Tabela 2. Wyniki analizy gęstości zaludnienia obszarów miejskich dla wszystkich gmin miejskich (oprac. E. Szymczyk)

| Years | 2006 | 2012 | 2018 |
|---|---|---|---|
| Number of observations | 964 | 964 | 964 |
| Median [people/km$^2$] | 2183.1 | 1970.24 | 1945.08 |
| Mean [people/km$^2$] | 2487.4 | 2232.33 | 2173.55 |
| Lowest outcome [people/km$^2$] | 451.86 | 388.22 | 464.36 |
| Highest outcome [people/km$^2$] | 5353.09 | 4730.06 | 4611.62 |

Table 3. Outcomes of compactness index analysis of urban areas in all urban municipalities (kind 1, kind 3) (elaborated by E. Szymczyk)
Tabela 3. Wyniki analizy indeksu zwartości zabudowy dla obszarów miejskich we wszystkich gminach miejskich (rodzaj 1, 3 wg. GUS BDL) (oprac. E. Szymczyk)

| Years | 2006 | 2012 | 2018 |
|---|---|---|---|
| Number of observations | 964 | 964 | 964 |
| Median | 0.1962 | 0.1912 | 0.1895 |
| Mean | 0.2239 | 0.2177 | 0.2158 |
| Lowest outcome | 0.0864 | 0.0929 | 0.0917 |
| Highest outcome | 0.4478 | 0.4251 | 0.4195 |

Secondly, the urban density of urbanised areas in Polish municipalities over time was compared. Similar to compactness, change over the years for all municipalities and urban municipalities shows a trend of significant decrease in urban population densities (Figs. 4a, b). Interestingly, the densest Polish urban municipality in 2006 – Sopot, with over 5894 people/km$^2$ was decreasing its density to reach 5413 people/km$^2$ in 2018. The densest urban municipalities in 2006 were Sopot, Świętochłowice and Chełmno. In 2012 and 2018, Wejherowo, Chełmno and Sopot with over 5 thousand people/km$^2$. For comparison, the densest European city and one of the densest in the world among mega cities – Paris, has an urban population density of 20 641 people/km$^2$. Table 3 shows detailed outcomes of the analysis, revealing the decrease in the urban population density in all urban municipalities.

The outcomes of compactness analysis for medium-sized and large cities (population over 20,000) were related to the urban municipality's population size. Figure 5 shows a clear logarithmic relationship of medium-sized cities being more compact than the big ones.

A similar relation analysis was conducted for the urban population density (Fig. 6). Conversely, the urban population density of bigger cities is higher, showing a clear logarithmic trend.

## Discussion

This research contributes to the study of urban compactness in Poland, being the first to employ a shape measure to assess the compactness of all urban municipalities in the country. Previous studies have predominantly focused on

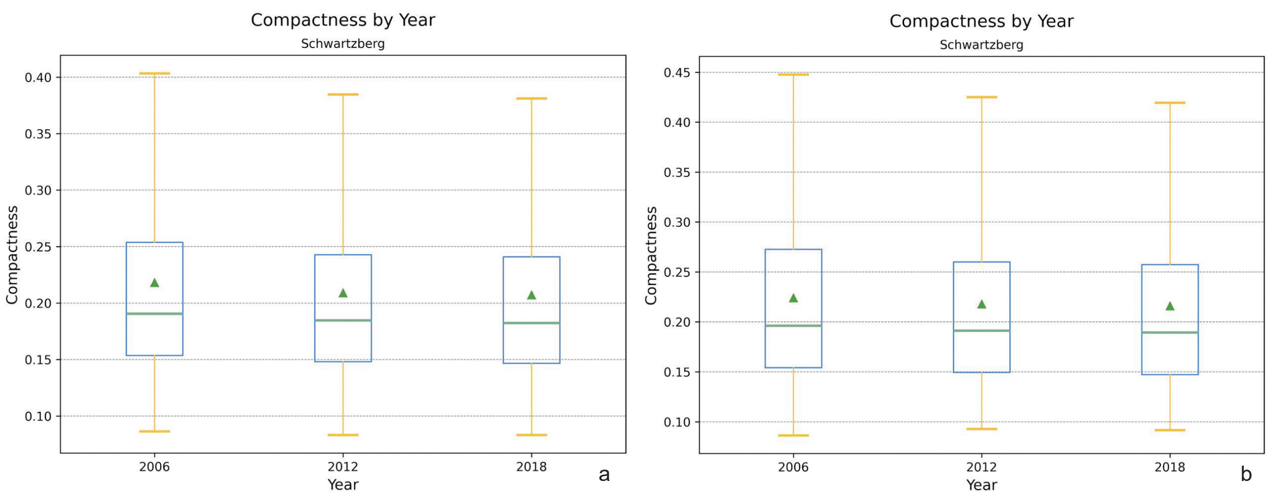


Fig. 4. Urban population density trend for: a) all municipalities, b) all urban municipalities (elaborated by E. Szymczyk)

Il. 4. Trend gęstości zaludnienia dla wszystkich polskich: a) gmin, b) gmin miejskich (oprac. M. Bukowski, E. Szymczyk)

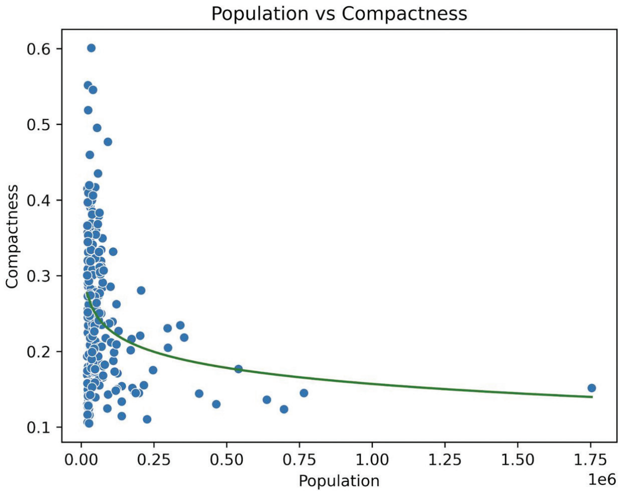


Fig. 5. Urban compactness trend for medium-sized and big urban municipalities in 2018 (elaborated by M. Bukowski)

Il. 5. Trend zwartości zabudowy w średnich i dużych gminach miejskich w 2018 r. (oprac. M. Bukowski)

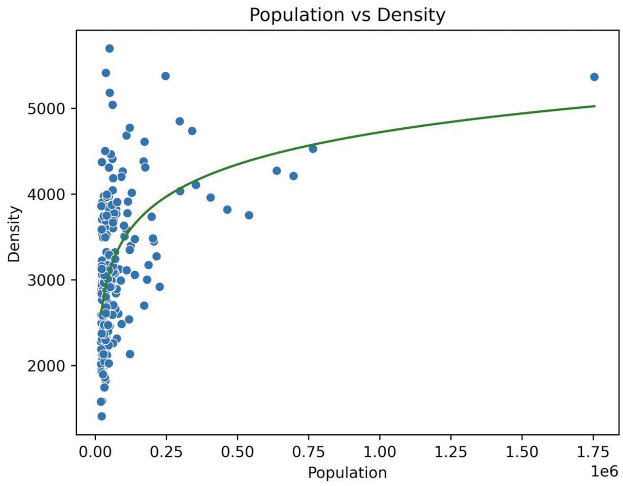


Fig. 6. Urban population density trend for medium-sized and big urban municipalities in 2018 (elaborated by M. Bukowski)

Il. 6. Trend gęstości zaludnienia obszarów miejskich w średnich i dużych gminach miejskich w 2018 r. (oprac. M. Bukowski)

urban sprawl, often limited to a smaller scope of cities (for example, Śleszyński 2014; Lityński 2021). Leveraging GIS and information technology tools enabled the management of extensive data sets across numerous municipalities, providing a comprehensive analysis of all urban areas over three distinct years for which spatial data was available in CLC. This chapter discusses the findings concerning the primary research questions.

## *Methods for analysing the compactness of Polish cities*

The methodology utilised in this study combines the widely used measure of urban population density with an urban shape measure based on the assumption that a circle represents the most compact geometric shape. It uses CLC- an open-sourced pan-European land use database in combination with population data (GUS). The integration of these measures proved effective in analysing compactness at a national scale. The shape measure, in particular, offers a novel approach in the Polish context, allowing for a more nuanced understanding of urban form beyond simple population density metrics. There is a considerable overlap between compactness index and urban population density measures concerning the geographic concentration of the most compact and densest urban areas.

In addition, there is a strong correlation between the two measures. Pearson's correlation between Ud and Ci was carried out for the three data sets. The results for all urban municipalities (urban and urban-rural) for the 2006 data showed an *r*-value correlation of 0.45 with a statistically significant *p*-value. In 2012, the correlation value increased to 0.48. In the most recent period, the coefficient remained at 0.48. This strong relationship is related to the fact that both measures have the same urban area component (Ad in the compactness index and Ua in urban density). It also proves that the measures represent the same urban phenomenon.

Both measures exhibit a significant decrease over time. These observations confirm that these measures describe a similar concept. Moreover, the presented outcomes of density relation with size are in line with research conducted by Śleszyński (2014), which showed a strong correlation between the density of a city's central area and city size. However, it has to be noted that this measure, while sufficient for general nation-scale research, is not sufficiently detailed for detailed studies. This is because there are discrepancies between land classes identified by CLC and the actual land uses. For example, according to the study of Śleszyński, Gibas and Sudra (2020), there is a mismatch, especially in the urbanised areas classification. While this method's alignment with existing literature supports its validity, future improvement is required. Further research should try to eliminate these discrepancies by reaching for different data.

## *Relationship between city size and compactness*

The analysis reveals that compactness is more prevalent in medium-sized urban municipalities, whereas urban population density is higher in larger urban municipalities, with Warsaw being a notable outlier. However, there is a significant geographic overlap between the most compact and densest urban areas, particularly in the southern edge and above the central belt of Poland (Fig. 7). The Kujawsko-Pomorskie voivodeship exhibits the most compact and densest municipalities, with neighbouring regions like Mazowieckie, Pomorskie, and northern parts of Lodzkie sharing this concentration. Conversely, lowland areas show a sparse distribution of compact and dense cities, while mountainous regions in the south and the lakelands

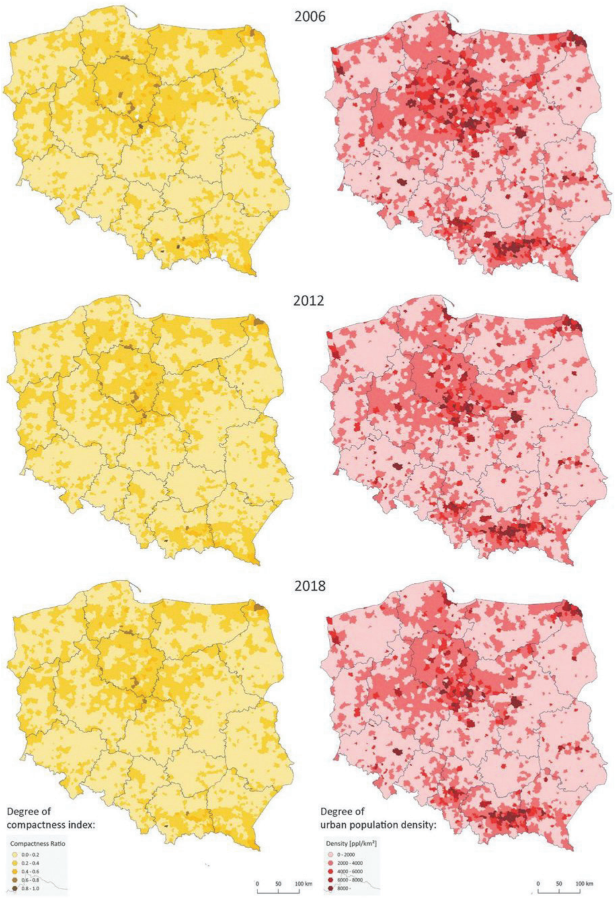


Fig. 7. The compactness index (left)
and urban population density calculation (right)
for all Polish municipalities in three periods
based on CLC datasets and Polish Statistics
(elaborated by M. Bukowski, E. Szymczyk)

Il. 7. Indeks zwartości (po lewej) oraz obliczenia gęstości zaludnienia
obszarów miejskich (po prawej) dla wszystkich polskich gmin
w trzech okresach, na podstawie danych CLC i statystyk GUS
(oprac. M. Bukowski, E. Szymczyk)

have higher concentrations. Moreover, the voivodeship with sparse populations, such as the northeastern corner of Poland, exhibits high-density urban areas. These findings suggest that historical context and topography play crucial roles in shaping urban compactness and pave the way for future research on the causes of compact urban patterns.

### *Changes in compactness over time*

This study provides evidence that the compactness of Polish urban areas is declining over time. Both compactness and urban population density measures demonstrate significant decreases, suggesting an ongoing trend towards urban dispersion. This trend poses environmental and economic risks, as highlighted by Lityński (2021), Śleszyński (2014) and Schiller and Kenworthy (2018), among others, and challenges the sustainability of urban development. The implications are particularly concerning in the context of declining demographic rates and urban shrinkage in Poland (Szymczyk, Bukowski 2023). Shrinking cities find it harder to maintain excess infrastructure in low-density areas. Research on shrinkage sprawl in the Polish context should follow to keep track of urbanisation patterns to effectively manage this phenomenon's negative effects.

### *Research limitations*

It has to be noted that this study did not account for topographical features such as bodies of water or forests, which constrains urban area development (making it more compact), nor did it consider the relationship to the CBD or historic city cores (Ottensmann 2021). Moreover, this study shows that the most compact cities are part of a bigger urban area with administrative boundaries "cutting" the shape out. Such cities, e.g., Ząbki and Podkowa Leśna around Warsaw, can be seen around big metropolitan areas. It would not be fair to see them as separate compact entities in the same way as Kościan, a city which is not bordering any big urban area, nor is it shaped by natural features. This leads to the conclusion that urban delimitation in future studies may try to use the concept of functional areas instead of administrative boundaries. As defined by the OECD (Moreno-Monroy, Schiavina and Veneri 2021), functional urban areas (FUAs) take into account the connections between cities and their surroundings. This may help to capture suburban sprawl more accurately than presented in this study.

Moreover, this study acknowledges the discrepancies between land uses, which tend to be overly generalised in CLC. Future research could benefit from incorporating these factors and improving the accuracy. Exploring morphological aspects like street connectivity building density (Burton 2002) and combining it with economic and functional aspects of compactness warrant further investigation. Moreover, population data coming from municipal data allowed for a generalised urban density calculation. This could be improved by using population data with more precise geolocation.

In conclusion, this study provides a robust framework for analysing urban compactness in the European context, offering valuable insights into the spatial dynamics of urban areas, such as the spatial implications of planning policies or economic processes. Since CLC datasets cover all European Union member states, this method is replicable in every member state, allowing for further comparative studies. The findings underscore the need for tailored urban policies that address the challenges of urban dispersion and promote sustainable urban development.

## ***Summary***

This study contributes to the state of knowledge by introducing and testing a shape measure to assess urban compactness across urban areas, offering a general but comprehensive national analysis. The research reveals that compactness in Poland is falling over the analysed time between 2006 and 2018. It shows that smaller urban municipalities are more compact in shape, whereas larger municipalities exhibit a logarithmic pattern of higher urban population density. Geographic patterns indicate that compact cities are more concentrated in Poland's southern and central regions.

Despite these advancements, the measure should have considered factors such as functional urban areas, topography, the location of a city in relation to other cities (free standing or adjacent) and the aspects of proximity of urban areas to city centres. Future research should also incorporate morphological factors like street connectivity, building density, building typologies, and economic and functional aspects of compactness. Addressing these limitations will enhance understanding of urban dynamics and inform more effective urban planning and policy-making, contributing to more sustainable development patterns in the context of climate change as well as in times of demographic and urban shrinkage.

## *References*

Ahlfeldt, Gabriel, and Elisabetta Pietrostefani. "The compact city in empirical research: A quantitative literature review". *SERC Discussion Paper*, 215 (2017). Accessed March 10, 2024, at https://eprints.lse.ac.uk/83638/1/sercdp0215.pdf.

Altman, Micah. "Districting Principles and Democratic Representation." Ph.D thesis. California Institute of Technology, 1998. https://doi.org/10.7907/7ZE9-TH19.

Barnes, Richard, and Justin Solomon. "Gerrymandering and Compactness: Implementation Flexibility and Abuse." *Political Analysis* 29, no. 4 (2021): 448–66. https://doi.org/10.1017/pan.2020.36.

Burton, Elisabeth. "Measuring Urban Compactness in UK Towns and Cities." *Environment and Planning B: Planning and Design* 29, no. 2 (2002): 219–50. https://doi.org/10.1068/b2713.

Chambers, Christopher P., and Allan D. Miller. "A Measure of Bizarreness." *Quarterly Journal of Political Science* 5, no. 1 (2010): 27–44. http://dx.doi.org/10.1561/100.00009022.

CLC. "Corine Land Cover Data." Accessed March 20, 2023. https://land.copernicus.eu/en/products/corine-land-cover.

Dantzig, George B., and Thomas L. Saaty. *Compact City: A Plan for a Liveable Urban Environment*. WH Freeman, 1973.

GUGiK. "Geodesy and Cartography Data." Accessed March 20, 2024, at https://www.gov.pl/web/gugik-en.

GUS BDL. 2023. "Statistics Poland Data." Accessed March 1, 2023, at https://bdl.stat.gov.pl/bdl/start.

Lityński, Piotr. "The Intensity of Urban Sprawl in Poland." *ISPRS International Journal of Geo-Information* 10, no. 2 (2021): 95. https://doi.org/10.3390/ijgi10020095.

Moreno-Monroy, Ana, Marcello Schiavina, and Paolo Veneri. "Metropolitan Areas in the World: Delineation and Population Trends." *Journal of Urban Economics* 125 (2021): 103242. https://doi.org/10.1016/j.jue.2020.103242.

Mubareka, Sarah, Eric Koomen, Christine Estreguil, and Carlo Lavalle. "Development of a composite index of urban compactness for land use modelling applications." *Landscape and Urban Planning* 103, no. 3–4 (2011): 303–17. https://doi.org/10.1016/j.landurbplan.2011.08.012.

Newman, Peter, and Jeffrey Kenworthy. *Cities and Automobile Dependence: An International Sourcebook*. Gower, 1989.

Niemi, Richard G., Bernard Grofman, Carl Carlucci, and Thomas Hofeller. "Measuring Compactness and the Role of a Compactness Standard in a Test for Partisan and Racial Gerrymandering." *The Journal of Politics* 52, no. 4 (1990): 1155–81. https://doi.org/10.2307/2131686.

OECD. "Compact City Policies A Comparative Assessment." Published 2012. Accessed March 20, 2024, at https://www.oecd.org/greengrowth/compact-city-policies-9789264167865-en.htm.

Ottensmann, John. *Measuring the Shape of Urban Areas.* Published February, 2021. Accessed March 20, 2024, at https://doi.org/10.13140/RG.2.2.28509.13288.

Reis, José P., Elisabete A. Silva, and Paulo Pinho. "Spatial metrics to study urban patterns in growing and shrinking cities." *Urban Geography* 37, no. 2 (2015): 246–71. https://doi.org/10.1080/02723638.2015.1096118.

Schiller, Preston, and Jeffrey Kenworthy. *An Introduction to Sustainable Transportation: Policy, Planning and Implementation.* Earthscan, 2018. https://doi.org/10.4324/9781315644486.

Schwarz, Nina, Dagmar Haase, and Ralf Seppelt. "Omnipresent Sprawl? A Review of Urban Simulation Models with Respect to Urban Shrinkage." *Environment and Planning B: Planning and Design* 37, no. 2 (2010): 265–83. https://doi.org/10.1068/b35087.

Schwartzberg, Joseph E. "Reapportionment, Gerrymanders, and the Notion of Compactness." *Minnesota Law Review* 50 (1966): 443–52.

Siedentop, Stefan, and Stefan Fina. "Urban Sprawl beyond Growth: the Effect of Demographic Change on Infrastructure Costs." *Flux*, no. 79–80 (2010): 90–100. https://doi.org/10.3917/flux.079.0090.

Song, Yu, Guofan Shao, Xiaodong Song, Yong Liu, Lei Pan, and Hong Ye. "The Relationships between Urban Form and Urban Commuting: An Empirical Study in China." *Sustainability* 9, no. 7 (2017): 1150. https://doi.org/10.3390/su9071150.

Squires, Gregory D., ed. *Urban Sprawl: Causes, Consequences, and Policy Responses*. The Urban Institute Press, 2002.

Szymczyk, Ewa, and Mateusz Bukowski. "Identification of Shrinking Cities in Poland Using a Multi-Criterion Indicator." *Przegląd Geograficzny* 95, no. 4 (2023): 447–73. https://doi.org/10.7163/PrzG.2023.4.5.

Śleszyński, Przemysław. "Distribution of population density in Polish towns and cities." *Geographia Polonica*, no. 1 (2014): 61–75. http://dx.doi.org/10.7163/GPol.2014.4.

Śleszyński, Przemysław, Piotr Gibas, and Paweł Sudra. "The Problem of Mismatch between the CORINE Land Cover Data Classification and the Development of Settlement in Poland." *Remote Sensing* 12, no. 14 (2020): 2253. https://doi.org/10.3390/rs12142253.

Thinh, Nguyen Xuan, Guenter Arlt, Bernd Heber, Joerg Hennersdorf, and Iris Lehmann. "Evaluation of urban land-use structures with a view to sustainable development." *Environmental Impact Assessment Review* 22, no. 5 (2002): 475–92. https://doi.org/10.1016/S0195-9255-(02)00023-9.

Tsai, Yu-Hsin. "Quantifying Urban Form: Compactness Versus 'Sprawl'." *Urban Studies* 42, no. 11 (2005): 141–61. https://doi.org/10.1080/00420980420003097.

"Uchwała nr 198 Rady Ministrów z dnia 20 października 2015 r. w sprawie przyjęcia Krajowej Polityki Miejskiej." MP 2015 poz. 1235. Accessed January 15, 2025, at https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wmp20150001235.

UN-HABITAT. "Envisaging the Future of Cities." Published 2022. Accessed March 20, 2024, at https://unhabitat.org/world-cities-report-2022-envisaging-the-future-of-cities.

## *Streszczenie*

***Kompaktowość polskich terenów zurbanizowanych – metody badań i analiza z użyciem bazy danych CLC***

W artykule autorzy przedstawili dynamikę kompaktowości (zwartości) zabudowy miejskiej w Polsce, analizując metody oceny tego zjawiska oraz zmiany zachodzące w czasie. Trzy główne pytania badawcze skoncentrowali wokół metod analizy zwartości, związku pomiędzy wielkością gmin miejskich a zwartością oraz zmian czasowych. Badaniem objęto wszystkie polskie gminy i zanalizowano wybrane miary zwartości w latach 2006, 2012 i 2018. Poprzez ocenę różnych metod analitycznych oraz wykorzystanie danych o użytkowaniu terenu z bazy CORINE Land Cover autorzy zaproponowali nową metodologię monitorowania wskaźników zwartości miast, wspierając tym samym podejmowanie decyzji planistycznych opartych na danych, dążąc do zrównoważonego planowania przestrzennego.

Wyniki ujawniają wzorce i korelacje pomiędzy wielkością miast a zwartością w czasie, wskazując na ogólny spadek zwartości zabudowy w badanym okresie (2006–2018). Wykazano istnienie logarytmicznego związku między wielkością populacji, indeksem zwartości i gęstością zaludnienia obszarów miejskich. Mniejsze miasta cechują się większą zwartością kształtu, ale niższą gęstością, natomiast większe miasta są gęściej zaludnione, lecz jednocześnie bardziej rozproszone. Praca wnosi wkład do stanu wiedzy, wprowadzając i testując metodę oceny zwartości zabudowy miejskiej w różnych typach gmin. Ponieważ dane CLC obejmują cały obszar Unii Europejskiej, metoda ta może być replikowana w każdym państwie członkowskim, umożliwiając dalsze badania porównawcze.

**Słowa kluczowe:** Polska, zwartość, kompaktowość, gęstość zaludnienia obszarów miejskich, CLC, metryki formy urbanistycznej